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The Effects of Imperfect Automation on Concurrent Performance of Gunner's and Robotic Operator's Tasks in a Simulated Mounted Environment

by Jessie Y.C. Chen and Peter I. Terrence

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14. ABSTRACT

In this study, we simulated a generic mounted environment and conducted an experiment to examine the performance and workload of the combined position of gunner and robotics operator. Aided target recognition (AiTR) (via tactile and visual cueing) with imperfect reliability (false alarm-prone versus miss-prone) was provided to the participants to aid their gunnery task. Besides the gunnery task, participants performed robotics and communication tasks concurrently. Results show that when the robotics task was simply monitoring the video feed, participants had the best performance in the other two concurrent tasks and the lowest perceived workload, compared with the other robotics tasking conditions. Our data also show that there is a strong interaction between the type of AiTR unreliability and participants' perceived attentional control. Overall, it appears that for high attentional control participants, false alarm-prone alerts were more detrimental than miss-prone alerts. For low attentional control participants, conversely, miss-prone automation was more harmful than false alarm-prone automation. Additionally, low spatial ability participants preferred visual cueing over tactile cueing, and high spatial ability participants favored tactile cueing over visual cueing.

15. SUBJECT TERMS

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1. Introduction

1.1 Purpose

The goal of this research was to examine the effects of unreliable alerts on gunners' concurrent performance of gunnery, robotics, and communication tasks. We simulated a generic mounted (i.e., tank) crew station environment and incorporated tactile and visual displays to provide directional cueing for the gunnery targeting task (based on simulated aided target recognition [AiTR] capability). Two types of imperfect AiTR were simulated: false-alarm prone (FAP) and miss-prone (MP). Effects of individual differences such as spatial ability (SpA) and perceived attentional control (PAC) were also evaluated. We were also interested in investigating discrepancies in previous research related to compliance and reliance effects as a function of type of AiTR error.

1.2 Background

The current U.S. Army Future Combat Systems (FCS) concept for the Mounted Combat System (MCS) is that it will be operated with a crew of three Soldiers: a vehicle commander, driver, and gunner; however, there is no dedicated operator to control the platoon's unmanned ground vehicle (UGV) (TRADOC, 2003). To examine how the MCS crew can effectively employ its UGV and which crew member should serve the role as the robotics operator, Mitchell (2005) conducted a workload analysis, using the Improved Performance Research Integration Tool (IMPRINT) to model the workload of each crew member if s/he has to concurrently operate a UGV. Mitchell found that the gunner had the fewest instances of overload and could assume control of the UGV and its associated tasks. However, there were instances in the model when the gunner dropped his or her primary tasks of detecting and engaging targets to perform robotics control tasks, which could be catastrophic for the team and mission during a real operation. Additionally, in scenarios when the UGV required tele-operation, the gunner was found to be consistently in overload, making concurrent performance of other tasks even more challenging.

In order to further investigate issues derived from Mitchell's IMPRINT analysis and to verify its results, we conducted a series of three simulation experiments to examine the mental workload and performance of the combined position of robotics operator and gunner. In the first study, we found that when the robotics operator must perform robot targeting and local security (i.e., gunner's tasks) at the same time, both workload and performance degraded (Chen & Joyner, 2006). Our results showed that a gunner's target detection performance degraded significantly when participants had to concurrently monitor, manage, and tele-operate a UGV, compared with the baseline condition when they only had to perform the gunnery task. As the robotics task became more challenging, participants' gunnery performance degraded accordingly. Their gunnery performance

was worst when they had to tele-operate a robot simultaneously. For the robotics tasks, participants' performance was lowest when they controlled a semi-autonomous UGV (only 53% of the targets were detected). Participants' perceived workload was lowest in the single task condition. There were three types of robotics tasks: Monitor, Auto, and Teleop. As the robotics task became more difficult, participants' workload increased accordingly, with the Teleop condition being the highest.

In the second study (Chen & Terrence, 2007), we examined if and how reliable tactile cueing, which delivered AiTR information to aid the operator's gunnery task, enhanced a gunner's performance in a multi-tasking environment similar to Chen and Joyner's (2006). We found that participants' gunnery task performance improved significantly when it was assisted by AiTR. Those participants with higher SpA outperformed those with lower SpA, especially when there was no AiTR. It was also found that significantly fewer neutral targets (which were not cued) in the gunnery environment were detected (implying less visual attention being devoted to the gunnery station) when participants concurrently tele-operated a robotic asset or when the gunnery task was assisted by AiTR. The most likely reason for this was that AiTR cueing increased task switching efficiency between the primary (gunnery) and secondary (robotics) tasks. However, this improved effectiveness for the gunnery and robotics tasks had a deleterious effect on the uncued neutral targets. Participants' concurrent task performance (i.e., robotics and communication) improved significantly when the gunnery task was assisted by AiTR. It was also found that the overall performance gap (including gunnery and robotics) between those participants with higher and lower SpA appeared to be narrower when the AiTR was available. A similar pattern was also observed for the PAC factor. Finally, participants' perceived workload was significantly influenced by the type of robotics tasks and whether the gunnery task was assisted by AiTR. Partici-pants' perceived workload was significantly higher when they tele-operated a robotic asset and when their gunnery task was unassisted. In a post-experimental survey, 65% of the participants indicated that they relied predominantly on the tactile cues when tactile and visual displays were available; only 15% said they relied primarily on the visual cues. Those who preferred visual cueing tended to have lower SpA, and their gunnery and robotics task performance tended to be inferior.

1.3   Imperfect Automation and Multi-tasking Performance

As described previously, Chen and Terrence (2007) demonstrated the utility of reliable AiTR for enhancing the operator's automated and concurrent tasks. However, since no AiTR systems can have perfect reliability, Chen and Terrence (2007) can only provide us an estimate of optimal condition when the alert is highly reliable. In the real world, cueing systems are often FAP or MP, based on the threshold settings of the alert. Wickens, Dixon, Goh, and Hammer (2005) showed that the operator's automated task (i.e., system failure monitoring) performance degraded when the false alarm (FA) rate of the alerts for the automated task was high. In other words, high FA rate reduced the operator's compliance with automation (compliance defined as taking actions based on the alerts). Conversely, when the miss rate was high, the concurrent task performance was affected

more than the automated task because the operator had to allocate more visual attention to monitor the automated task. In other words, a high miss rate reduced the operator's reliance on automation (reliance defined as failure to take precautious actions when there is no alert). Similarly, Dixon and Wickens (2006) showed that FAs and misses affected compliance and reliance, respectively, and their effects appeared to be relatively independent of each other. In contrast, Dixon, Wickens, and McCarley (2007) showed that FAP automation hurt "performance more on the automated task than did MP automation, (e.g., the "cry wolf" effect) and hurt performance (both speed and accuracy) at least as much as MP automation on the concurrent task (p. 570-571)." FAP automation was found to affect operator compliance and reliance, while MP automation affected only operator reliance. The authors suggested that the FAP automation had a negative impact on reliance because of the operator's overall reduced trust in the automated system. Similarly, Wickens, Dixon, and Johnson (2005) demonstrated a greater cost associated with FAP automation (than with MP automation), which affected the automated and concurrent tasks.

Furthermore, Wickens and Dixon (2005) demonstrated that when the reliability level is below about 70%, operators often ignore the alerts. In their meta-analytic study, Wickens and Dixon found that "a reliability of 0.70 was the 'cross-over point' below which unreliable automation was worse than no automation at all." Although Wickens and his colleagues have done extensive research in this area, their studies were done in a different environment (unmanned aerial vehicle control display monitoring), and they did not use tactile cueing. The current study was the first one to examine these issues in the context of combined roles of gunner and robotics operator. Since an AiTR cannot have a perfect reliability rate in foreseeable real-world operations, the data from this study should provide useful information to the design community of future systems such as the FCS, in which AiTR will play an integral role (see Chen & Terrence, 2007, for a detailed discussion of the utility of tactile display for AiTR cueing).

1.4 Individual Differences

In the current study, we sought to investigate the effects of individual differences factors such as SpA and PAC on the operators' concurrent performance. Previous studies (Chen et al., in press; Chen & Joyner, 2006) found that SpA was correlated with robotics and gunnery task performance. Lathan and Tracey (2002) demonstrated that people with higher SpA performed better in a teleoperation task through a maze. They finished their tasks faster and had fewer errors. Lathan and Tracey suggested that military missions can benefit from selecting personnel with higher SpA to operate robotic devices. In addition to SpA, we examined the relationship between attentional control and multi-tasking performance. Derryberry and Reed (2002) showed that those with higher attentional control could switch their attention among tasks more effectively and this was partially confirmed by Chen and Joyner (2006) and Chen and Terrence (2007). There is some evidence that attention-switching flexibility can predict performance of such diverse tasks as flight training and bus driving (Kahneman, Ben-Ishai, & Lotan, 1973). Several studies show that there are individual differences in multi-tasking performance, and some people are less prone to

performance degradation during multi-tasking conditions (Rubinstein, Meyer, & Evans, 2001; Schumacher et al., 2001).

1.5 Current Study

In the current study, we replicated the conditions of Chen and Joyner (2006) and manipulated the reliability of the AiTR cueing system (i.e., false alarm and miss rates). Based on the data from Wickens, Dixon, Goh, and Hammer (2005), we expected that the operator's gunnery (automated) task performance would degrade if the FA rate of the AiTR for the gunnery system were high because of reduced compliance with the automation. Conversely, if the cueing were MP, the operator's robotics (concurrent) task performance would be affected more than the gunnery task because of reduced reliance on the automation. More mental and visual resources would be devoted to checking the raw data for the automated task, and therefore, the performance of the concurrent task would be degraded. On the other hand, there was evidence that FAP automation was more detrimental to the automated and concurrent tasks than MP automation (Dixon et al., 2007). Therefore, it is likely that FAP automation would have a more negative impact on the overall performance than would MP automation. In other words, there have been conflicting results in the literature regarding the independence of the effects of FAP and MP automation on operator compliance and reliance. It is possible that individual differences may be responsible for some of the observed differences in the literature. Therefore, we investigated the effects of individual differences on FAP and MP conditions as a possible explanation for the discrepancies. Additionally, in Chen and Terrence (2007), we observed that low SpA participants indicated that they preferred visual cueing when visual and tactile cueing displays were available, whereas high SpA participants favored tactile cueing over visual cueing. In the current study, visual and tactile cueing were presented. The relationship between SpA and preference of AiTR display modality was examined.

2. Method

2.1 Participants

A total of 24 students (4 females and 20 males) was recruited from the University of Central Florida and participated in the study. The ages of the participants ranged from 18 to 34 (mean [M] = 22.25, standard deviation [SD] = 4.0). Participants were compensated $15/hr and/or class credit for their participation in the experiment.

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2.2   Apparatus

2.2.1 Simulators

2.2.1.1 Tactile Control Unit (TCU)

The experiment was conducted with a TCU developed by the U.S. Army Research Laboratory's (ARL's) Robotics Collaborative Technology Alliance (RCTA) for the robotic control tasks. The TCU is a one-person crew station from which the operator can control several simulated robotic assets that can perform their tasks semi-autonomously or be tele-operated (see figure 1). The operator switched operation modes and display modes through the use of a 19-inch touch-screen display. A joystick was used to manipulate the direction in which the unmanned vehicles moved when in Teleop mode. The UGV simulated in our study is the experimental unmanned vehicle developed by ARL. The simulation program used in this study was rSAF (robotic semi-automated forces), which is a version of OneSAF for robotics simulation.

Figure 1. User interface of RCTA TCU.

2.2.1.2 Gunnery Station

The gunnery component was implemented with an additional screen and controls to simulate the out-the-window (OTW) view and line-of-sight (LOS) fire capabilities. The interface consisted of a 15-inch flat panel monitor and a joystick (see figure 2). Participants used the joystick to rotate the sensors 360 degrees, zoom in and out, switch between firing modes, and engage targets. In each scenario, there were 10 hostile targets and 10 neutral targets (i.e., civilians) scattered throughout the simulated environment.
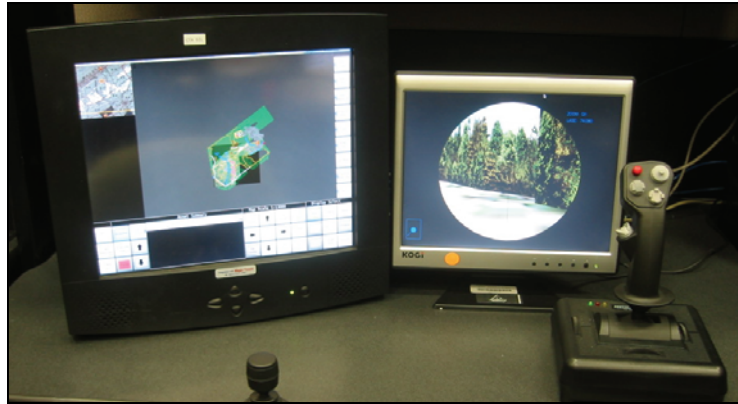
Figure 2. TCU (left) and gunnery station (gunner's OTW view) (right).

2.2.1.3 AiTR Systems - Tactile and Visual Alerts

To augment target detection in the gunnery component, visual and tactile alerts were used to cue the participant to the direction of a target, as determined by the AiTR. Visually, the targets consisted of icons presented around the overhead view diagram of the participant vehicle in the lower right area of the screen (see figure 3). The target icon appeared in one of eight possible locations around the gunner, corresponding to 45-degree increments along a 360-degree azimuth. As the gunner rotated the view, the turret portion of the vehicle diagram moved along the eight possible orientations to allow the gunner to place his/her field of view (FOV) on the cued target. Tactually, target positions relative to the gunner were presented via eight electromechanical transducers known as "tactors" (see figure 4). More details about the tactile display are given in Chen and Terrence (2007).

Figure 3. Visual cueing (red dot indicating the
direction of hostile target).
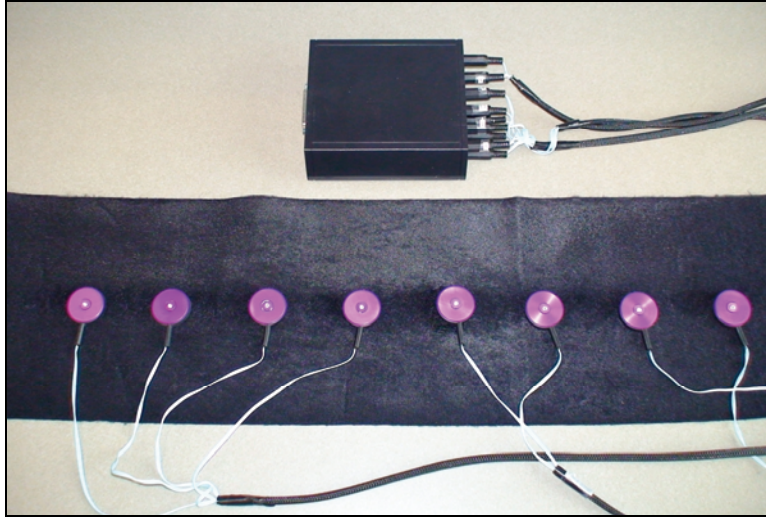
Figure 4. Tactile system.

2.2.2 Communication Task Materials

The communication task was administered concurrently with the experimental scenarios. The questions included simple military-related reasoning tests and simple memory tests. The inclusion of these cognitive tasks was for simulating an environment where the gunner was communicating with fellow crew members in the vehicle. For the reasoning tests, there were questions such as "if the enemy is to our left, and our UGV is to our right, what direction is the enemy to the UGV?" For the memory tests, the participants were asked to repeat some short statements or keep track of three radio call signs (e.g., Bravo 83) and they had to report to the experimenter whether the call signs they heard were one of those they were keeping track. Test questions were delivered by a synthetic speech program, DECTalk[1]. The questions were pre-recorded by a male speaker and presented at the rate of one question every 33 seconds.

2.2.3 Questionnaires and Spatial Tests

A demographics questionnaire was administered at the beginning of the training session (appendix A). A questionnaire about attentional control (appendix B) (Derryberry & Reed, 2002) was used to evaluate participants' PAC. The Attentional Control Survey (ACS) consists of 21 items and measures attention focus and shifting. The scale has been shown to have good internal reliability ($\alpha = .88$). Derryberry and Reed conducted an experiment to examine the relationship between self-reported (i.e., ACS score) and actual attentional control. They found that participants with a high ACS score could better resist interference in a Stroop-like spatial conflict task. In our previous studies (Chen & Joyner, 2006; Chen & Terrence, 2007), we observed a positive, although some-what weak, relationship between ACS score and some multi-tasking performance measures.

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[1]DECtalk is a registered trademark of Digital Equipment Corporation.

The Cube Comparison (Cube for short) and the Hidden Patterns tests (Educational Testing Service, 2007a&b) as well as the Spatial Orientation Test (Orientation for short) were used to assess participants' SpA. The Cube test requires participants to compare, in 3 minutes, 21 pairs of six-sided cubes and determine if the rotated cubes are the same or different. The Hidden Patterns test measures flexibility of closure and involves identifying specific patterns or shapes embedded within distracting information. The Orientation test, constructed by Dr. Paula Durlach of the U.S. Army Research Institute, is modeled after the Cardinal Direction test developed by Gugerty and his colleagues (Gugerty & Brooks, 2004) and is a computerized test consisting of a brief training segment and 32 test questions. Accuracy and response time were automatically captured by the program.

Participants' perceived workload was evaluated with the computer-based version of National Aeronautics and Space Administration Task Load Index (NASA TLX) questionnaire (appendix C) (Hart & Staveland, 1988). The NASA TLX is a self-reported questionnaire of perceived demands in six areas: mental, physical, temporal, effort (mental and physical), frustration, and performance. Participants were asked to evaluate their perceived workload level in these areas on 10-point scales. They also assessed the contribution (i.e., weight) of each factor to the perceived workload by comparing the 15 possible pairs of the six factors. According to Noyes and Bruneau (2007), computer-based NASA TLX tends to generate higher workload ratings compared with the traditional paper-based survey. However, since the ratings were used to compare the workload levels across the experimental conditions, the elevated ratings should not affect these comparisons.

Finally, a usability questionnaire about the tactile/visual AiTR displays was constructed (see appendix D). Participants indicated their level of reliance on tactile and/or visual cueing for the gunnery task when both types of alerts were available. They also indicated their perceived usability of the AiTR displays. Participants were also asked to evaluate their trust in the AiTR system using a modified survey by Jian, Bisantz, and Drury (2000) (appendix D, items 22-33).

2.3   Experimental Design

The overall design of the study is a 2 x 3 mixed design. The between-subject variable is AiTR type (FAP versus MP). The within-subject variable is Robotics Task type (Monitor versus Auto versus Teleop).

The reliability level of the FAP and MP alerts was 60%. The FAP condition consisted of 10 hits (i.e., alerts when there were targets), eight FAs (i.e., alerts when there were no targets), no misses (i.e., no alerts when there were targets), and two correct rejections (CRs) (i.e., no alerts when there were no targets). The MP condition consisted of two hits, no FAs, eight misses, and 10 CRs. Additionally, only hostile targets were cued, not the neutral targets. The participants were instructed to detect the neutral targets independently.

2.4 Procedure

After being briefed about the purpose of the study, the tasks for the experiment, and any risks involved, participants read and signed a consent form. They then answered the attentional control survey and were administered the spatial ability tests (i.e., Cube, Hidden Patterns, and Orientation). After these tests, participants received training, which was self-paced and was delivered by Power-Point[2] slides showing the elements of the TCU, steps for completing various tasks, several mini-exercises for practicing the steps, and two exercises for performing the robotic control tasks (one for practicing the tele-operation task and one for practicing the auto control tasks). After the tutorial on TCU, participants were trained in the gunnery tasks. Participants had to demonstrate that they could perform the tasks without any help. The entire training session lasted about 2.5 hours.

Before the experimental session began, participants changed into one of the laboratory cotton T-shirts in order to standardize how the tactors were applied to the skin. They chose a size and then were escorted to the restroom where they could change privately. After this was done, the experimenter asked to measure the participant around the abdomen just above navel height so that the tactile display could be custom fitted. After taking this measurement, the experimenter arranged the tactors so that they were equidistant for the participant's abdomen. Once fitted with the tactile display, the participant was seated in front of the gunner monitor. A test pattern confirmed that all eight tactors were working properly and that the participant could readily perceive the stimuli. The experimenter then explained the nature of the AiTR system and the corresponding visual or tactile cues that would be provided.

In the experimental trials, participants' tasks were to use their robotic asset to locate targets (i.e., enemy dismounted Soldiers) in the remote environment and to find targets in their immediate (i.e., MCS) environment. The MCS was simulated as traveling along a designated route, which was approximately 4.3 km and lasted about 15 minutes. There were 10 hostile and 10 neutral targets (i.e., civilians) along the route in each gunnery scenario. Participants were instructed to engage the hostile targets and verbally report spotting the neutral targets. In total, there were three 15-minute scenarios, corresponding to the three within-subject experimental conditions, the order of which was counterbalanced across participants.

There were three types of robotics tasks: Monitor, Auto, and Teleop. The Monitor task required the operator to continuously monitor the video feed as the UGV travels autonomously and to verbally report detection of targets. There were 20 targets (5 hostile and 15 neutral) along the route. The Auto control task required the operator to monitor the video feed as the UGV traveled autonomously, examine still images generated from the RSTA (reconnaissance, surveillance, and target acquisition) scans, and detect targets. The Teleop task required the operator to manually manipulate and drive the UGV (using a joystick) along a predetermined route using the TCU to detect targets. For both the Auto and Teleop tasks, there were, on average, two to four targets (one

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[2]PowerPoint is a trademark of Microsoft Corporation.

hostile plus one to three neutral targets) at each checkpoint. There were five checkpoints along the designated route. Upon detecting a target, participants needed to place the target on the map, label the target, and then send a spot report.

While the participants were performing their gunnery and robotics control tasks, they simultaneously performed the communication task by answering questions delivered to them via DECtalk.

There were 2-minute breaks between experimental scenarios. Participants assessed their workload using the NASA TLX after they completed each scenario. The entire experimental session lasted about 1 hour.

2.5 Measures

The dependent measures include mission performance (i.e., number of targets detected in the remote environment with the robotic asset and number of hostile/neutral targets detected in the immediate environment), communication task performance, and perceived workload.

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3. Results

3.1 Target Detection Performance

3.1.1 Gunnery Tasks

3.1.1.1 Hostile Targets

Table 1 lists several measures relating to operator task performance. A mixed analysis of variance (ANOVA) was performed to examine the effects of the concurrent robotic control tasks on the gunnery task performance (percentage of hostile targets detected), with the AiTR condition (FAP versus MP) being the between-subject factor and the Robotics Task condition (Monitor versus Auto versus Teleop) as the within-subject factor (see appendix E for the complete data). The analysis revealed that the Robotics condition significantly affected number of targets detected, $F(2, 15) = 4.578$, $p < .05$ (figure 5). *Post hoc* tests (least significant difference [LSD]) showed that target detection in the Monitor condition was significantly higher than in the Auto and Teleop conditions.

Table 1. Operator task performance (mean percent of targets detected for the gunnery and robotics tasks and percent correct for the communication task. (Standard deviations are presented in parentheses.)

Measures	FAP			MP		
	Monitor	Auto	Teleop	Monitor	Auto	Teleop
Gunnery Task (Hostile only)	.775 (.238)	.551 (.302)	.644 (.256)	.608 (.156)	.533 (.227)	.500 (.268)
Gunnery Task (Neutral only)	.325 (.166)	.442 (.178)	.319 (.171)	.583 (.255)	.467 (.267)	.413 (.226)
Robotics Task	.908 (.104)	.639 (.187)	.770 (.134)	.906 (.102)	.742 (.158)	.637 (.128)
Communication Task	.802 (.118)	.773 (.112)	.777 (.133)	.870 (.089)	.812 (.117)	.805 (.100)
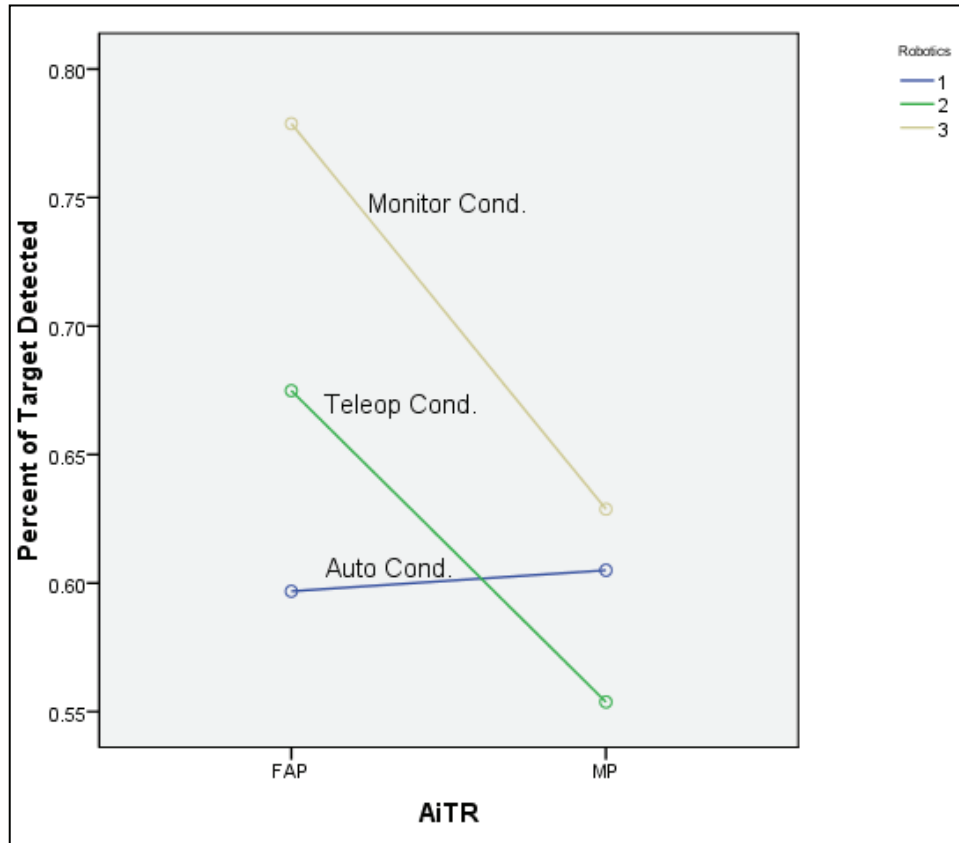
Figure 5. Gunnery task performance, hostile targets only.

The effects of participants' SpA and PAC were also evaluated. The analysis showed that participants with higher SpA had a significantly higher gunnery task performance than did those with lower SpA, $F(1, 16) = 6.311$, $p < .05$ (figure 6).

There was also a significant AiTR x PAC interaction, $F(1, 16) = 7.358$, $p < .05$ (figure 7). Those with a lower PAC had a better performance with the FAP cueing, and those with a higher PAC had a better performance with the MP cueing.

In order to further examine the effect of task load on reliance of AiTR, the data of the MP condition were analyzed separately. Because of the small sample size (N = 12), no significant differences were found between those with a high versus low PAC. However, the trend was evident that as task load became heavier (i.e., Teleop > Auto > Monitor, based on Chen & Joyner, 2006), those with a low PAC became increasingly reliant on the AiTR, while those with a high PAC maintained a fairly stable level of reliance throughout the experimental conditions (figure 8).
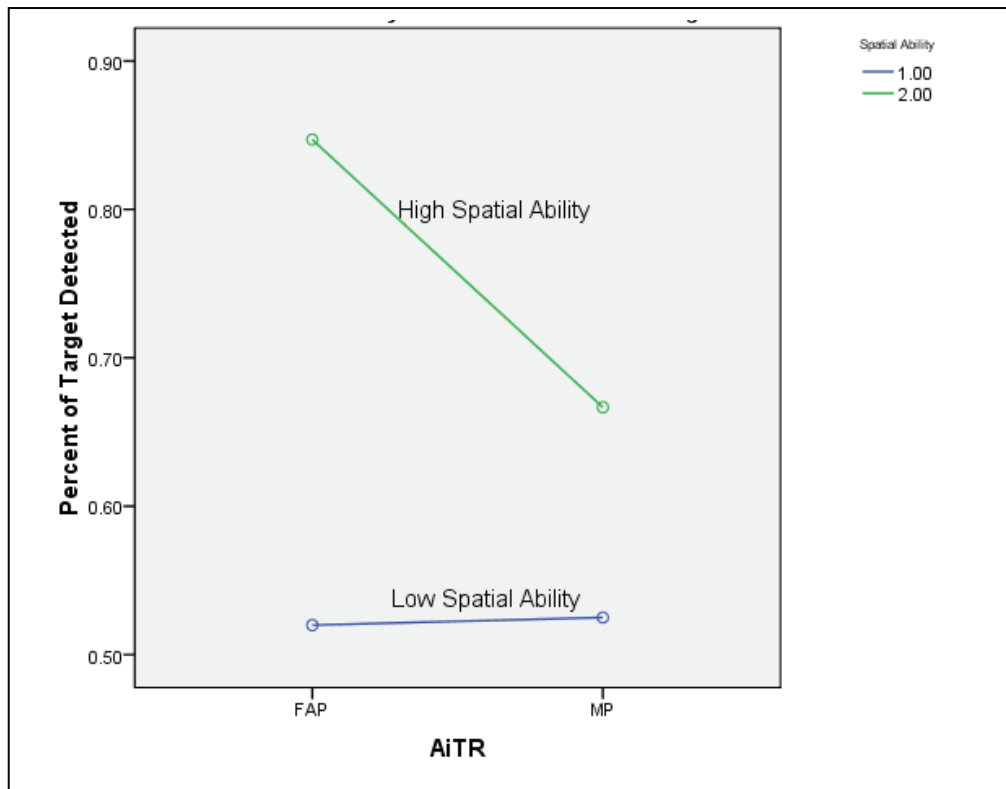
Figure 6. Effects of spatial ability on gunnery task performance, hostile targets only.
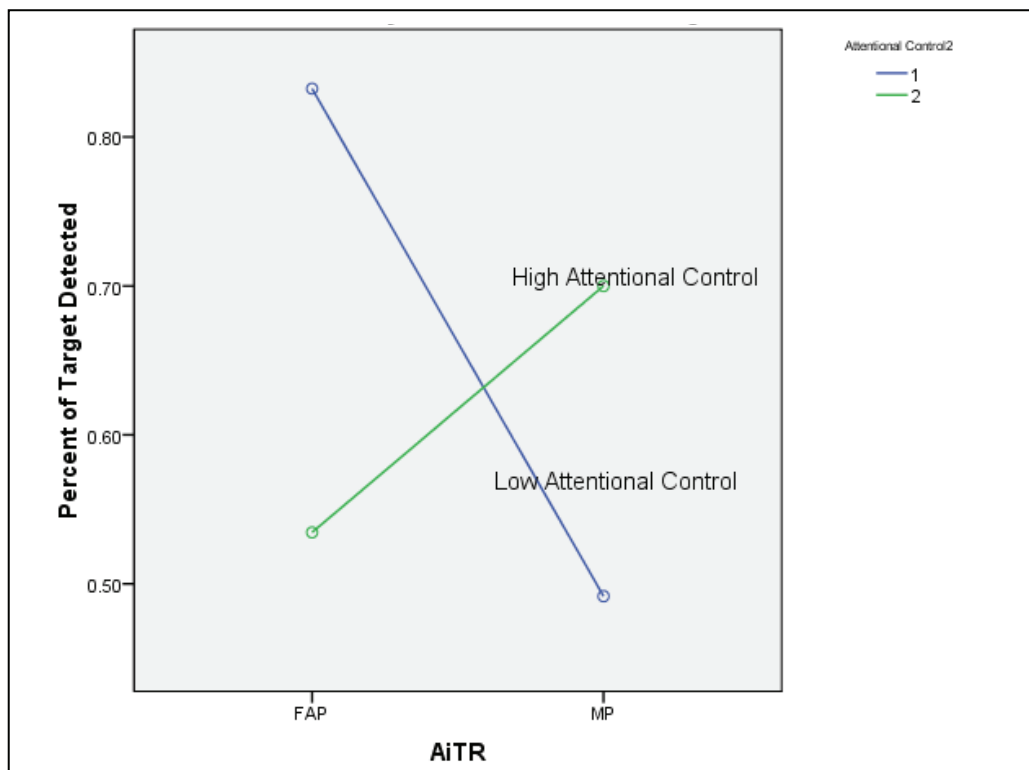
Figure 7. Effects of perceived attentional control on gunnery task performance, hostile targets only.
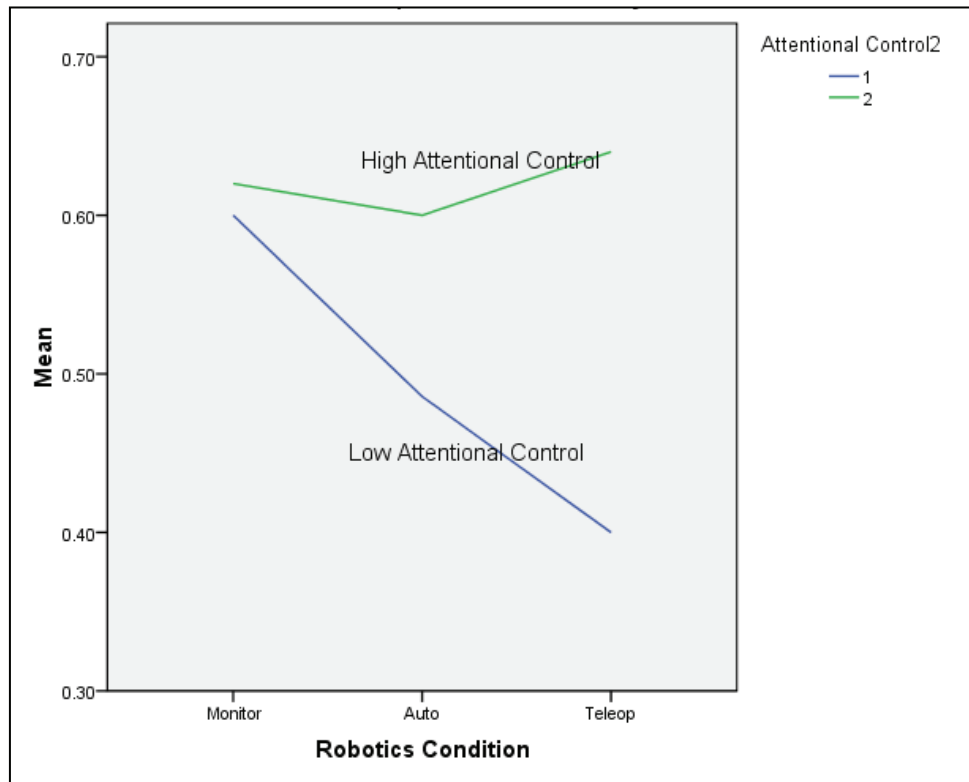
Figure 8. Effects of perceived attentional control on gunnery task performance (hostile targets only) in MP conditions.

3.1.1.2 Neutral Targets

Participants' detection of neutral targets was also assessed. Since the AiTR only alerted the participants when hostile targets were present, the neutral target detection could be used to indicate how much visual attention was devoted to the gunnery station. A mixed ANOVA revealed a significant main effect for Robotics, $F(2,15) = 4.362$, $p < .05$ (figure 9). *Post hoc* tests (LSD) showed that neutral target detection in the Teleop condition was significantly lower than in the Auto condition. There was also a significant AiTR x PAC interaction, $F(1, 16) = 3.602$, $p < .05$ (figure 10). Those with a lower PAC performed at about the same level, regardless of the AiTR type, while those with a higher PAC had a significantly better performance with the MP cueing.
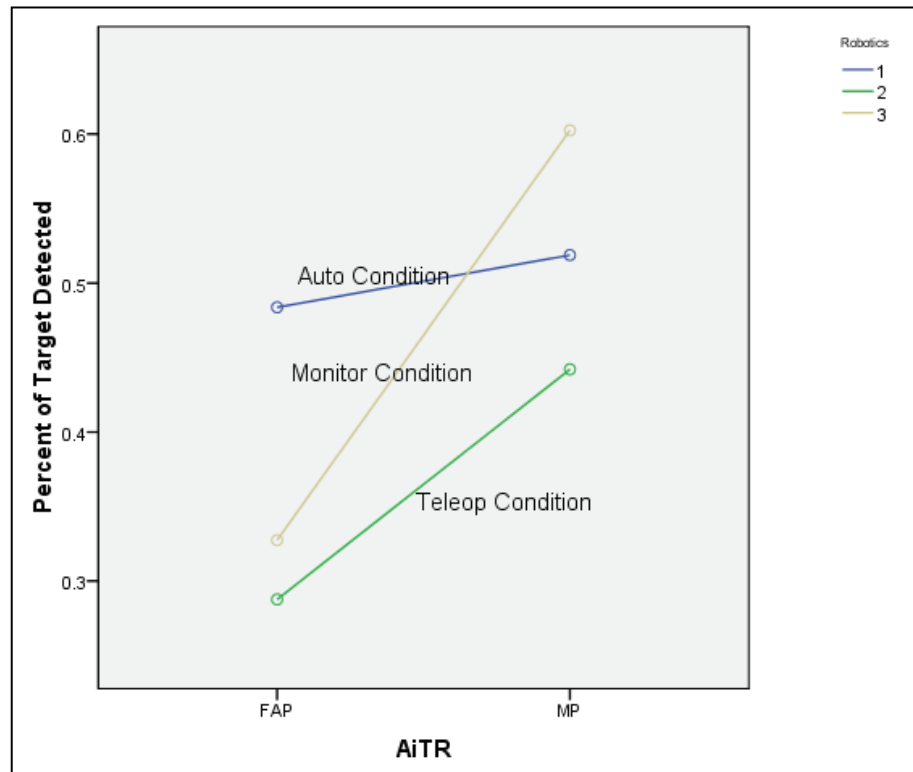
Figure 9. Gunner's neutral target detection performance.
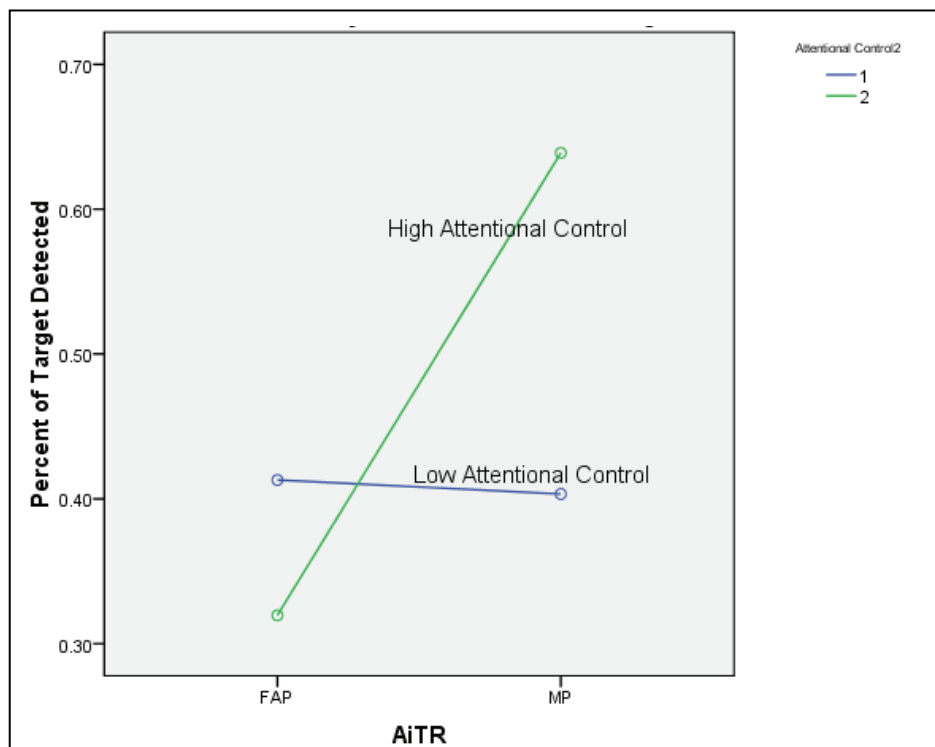
Figure 10. Effects of perceived attentional control on gunner's neutral target detection performance.

3.1.2 Robotics Tasks

A mixed ANOVA revealed that there was a significant main effect for Robotics, $F(2,15) = 25.357$, $p < .001$ (figure 11). It was found that the Monitor condition was significantly higher than both the Auto and the Teleop conditions in terms of percentage of targets detected. There was a significant Robotics x AiTR interaction, $F(2,32) = 3.96$, $p < .05$. The Monitor task performance stayed at the same level, regardless of the AiTR types. The Auto task performance was higher with the MP cueing, while the Teleop task performance was higher with the FAP cueing.
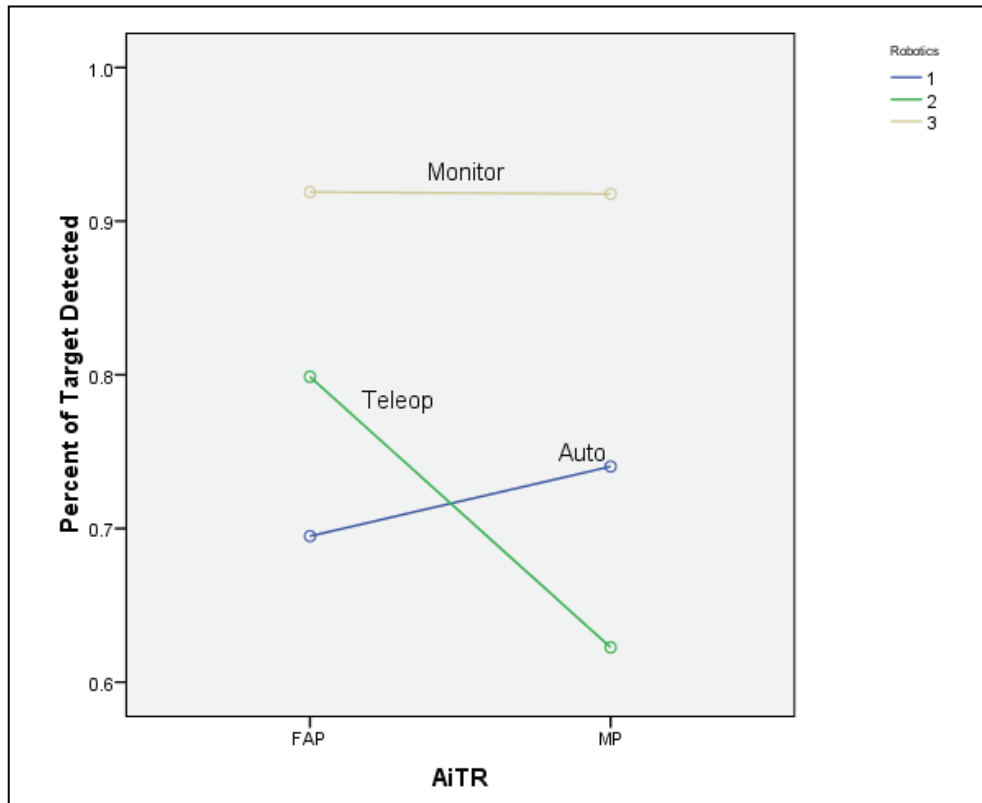
Figure 11. Robotics task performance.

There was also a significant AiTR x PAC interaction, $F(1,16) = 4.801$, $p < .05$ (figure 12). Those with a lower PAC had a better performance with the FAP cueing, while those with a higher PAC had a better performance with the MP cueing.
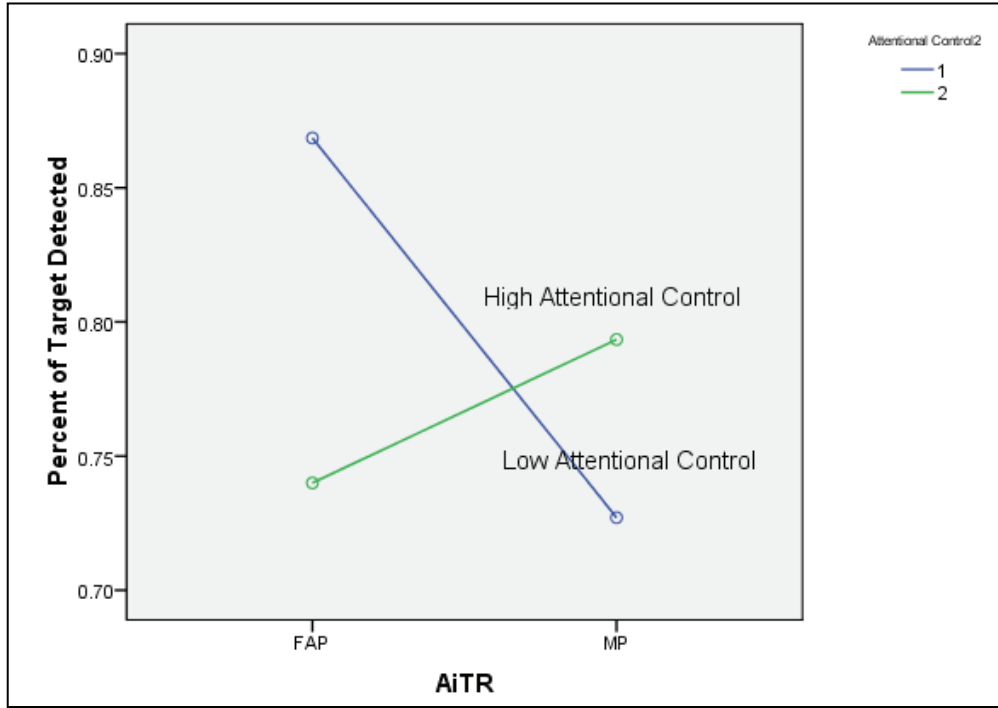
Figure 12. Effects of perceived attentional control on robotics task performance.

3.2 Communication Task Performance

A mixed ANOVA revealed that there was a significant main effect for Robotics, $F(2,44) = 3.247$, $p < .05$ (figure 13). It was found that the Monitor condition was significantly higher than the Teleop conditions.

3.3 Perceived Workload

Weighted ratings of the scales of the NASA TLX were used for this analysis. Participants' self-assessment of workload was significantly affected by Robotic condition, $F(2,15) = 25.057$, $p < .001$ (figure 14). The perceived workload was significantly higher in the Teleop condition ($M = 77.71$) than in the Auto condition ($M = 69.61$) and the Monitor condition ($M = 61.06$). The difference between Auto and Monitor was also significant. There was a significant Robotics x AiTR interaction, $F(2,15) = 5.464$, $p < .05$.
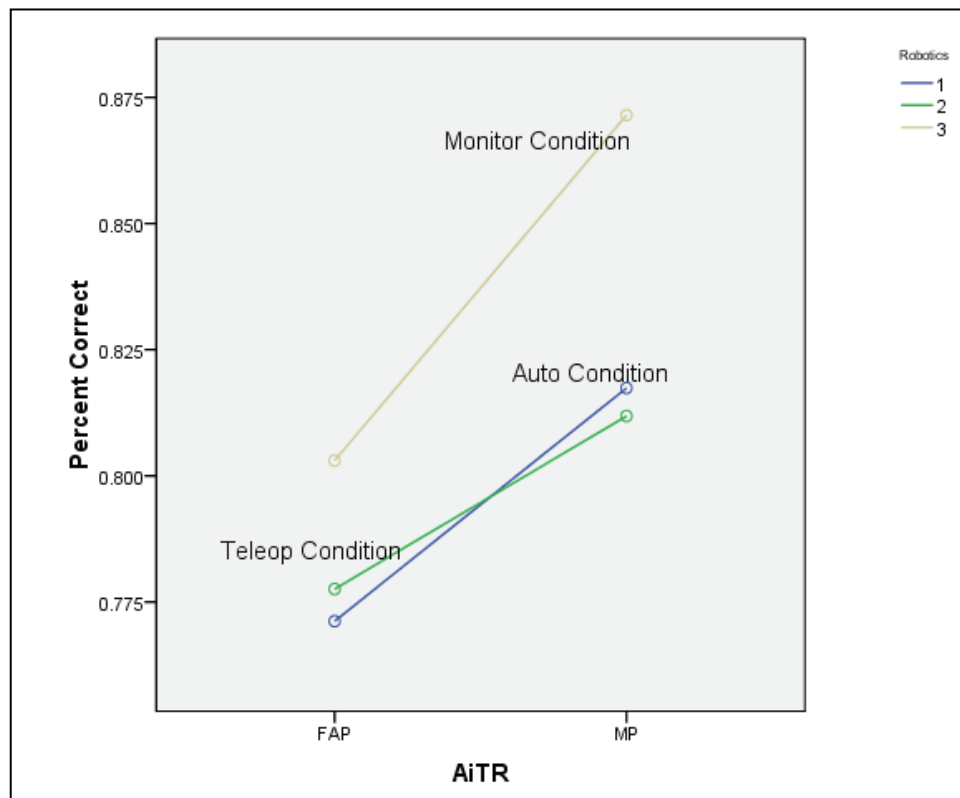
Figure 13. Communication task performance.
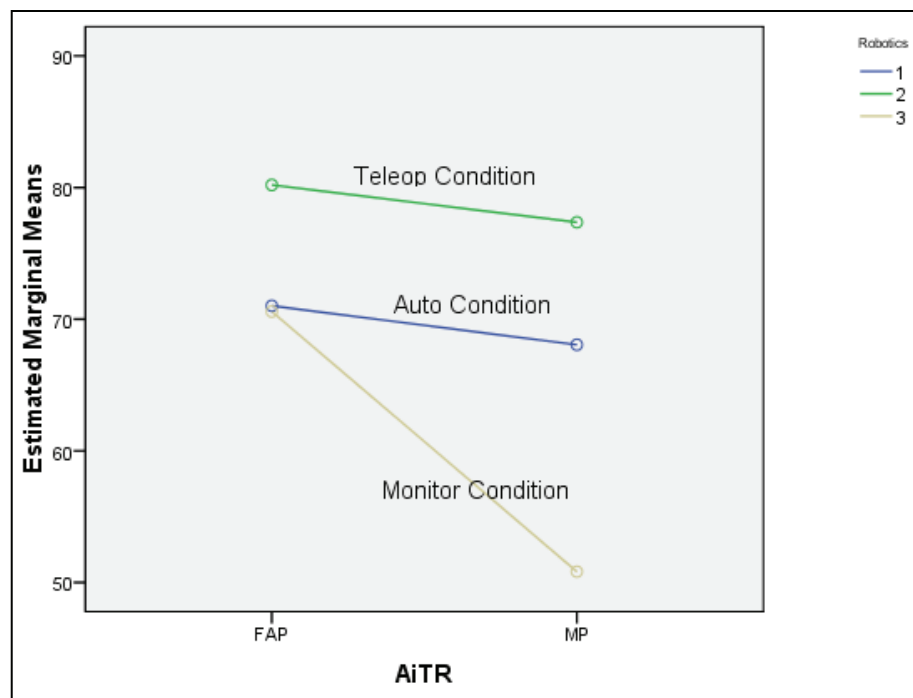
Figure 14. Perceived workload.

3.4 AiTR Display Assessment

A usability questionnaire captured participant preferences for the presentation of AiTR information. Following their interaction with the AiTR systems, 41% of participants responded that they relied predominantly or entirely on the tactile AiTR display, while 36% responded that they relied predominantly or entirely on the visual AiTR display. AiTR preference was also significantly correlated with SpA ($r = .507, p < .01$). Those with higher SpA tended to prefer tactile cueing over visual cueing. Conversely, those with lower SpA favored visual cueing over tactile cueing.

We also evaluated participants' self-assessed trust in the AiTR system and compared those with higher and lower PAC. There was no significant difference between these two groups.

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4. Discussion

In this study, we simulated a generic mounted environment and conducted an experiment to examine the performance and workload of the combined position of gunner and robotics operator. More specifically, we investigated the effects of AiTR with imperfect reliability (FAP versus MP) on the operator's performance of the automated (i.e., gunnery) task as well as the concurrent tasks (i.e., robotics and communication). Our most intriguing findings were related to the relationship of individual differences to predicted compliance and reliance performance. In order to simplify our discussion, we discuss effects of PAC differences on gunner performance for FAP and MP conditions and then discuss how these differences affected neutral targeting and secondary task performance (robotics and communication).

4.1 Gunnery Task Performance, Hostile Targets

Our results showed that the operator's gunnery task performance in detecting hostile targets was significantly better in the Monitor condition than in the other two robotics task conditions, consistent with the findings of Chen and Joyner (2006). In Chen and Joyner (2006) and the current study, the workload associated with the Monitor condition was significantly lower than the other robotics conditions (see section 4.5 for more discussion of workload). These results suggest that the operator had more visual and mental resources for the gunnery task when the robotics task was simply monitoring the video feed, compared with the other two robotics conditions.

Also consistent with the previous findings (Chen & Joyner, 2006; Chen & Terrence, 2007), participants' SpA was found to be an accurate predictor of their gunnery performance. Thomas and Wickens (2004) showed that there were individual differences in scanning effectiveness and its associated target detection performance. However, Thomas and Wickens did not examine the characteristics of those participants who had more effective scanning strategies. The findings of

the current study along with the previous two studies indicate that SpA may be an important factor for determining scanning effectiveness.

Our results also showed that there was a significant interaction between types of unreliable AiTR and participants' PAC. For those with high PAC, our data are consistent with the notion that operator reliance on and compliance with automation are independent constructs and are separately affected by system misses and false alarms. Based on figure 7, it is evident that high PAC participants did not comply with alerts in the FAP condition. Since the FAP AiTR had a 0% miss rate, a full compliance should result in a detection rate over 80%, as reported in Chen and Terrence (in which a perfectly reliable AiTR was used). As predicted, figure 7 shows that in MP conditions, high PAC participants did not rely on the AiTR and detected more targets than were cued. However, an examination of the data for the low PAC participants revealed a completely opposite trend. Specifically, with the FAP condition, low PAC participants showed a strong compliance with the alerts, which resulted in a good performance in target detection (at a similar level as in Chen and Terrence). With the MP condition, however, low PAC participants evidently overly relied on the automation and therefore had a very poor performance. Figure 8 shows that as task load became heavier, those with low PAC became increasingly reliant on the AiTR, while those with high PAC maintained a fairly stable level of reliance throughout the experimental conditions. According to Biros, Daly, and Gunsch (2004), higher task loads tend to induce a higher level of reliance on automated systems. Our present data suggest that this heightened level of reliance is also moderated by PAC. More specifically, only those with low PAC tend to exhibit over-reliance on automation under a heavy task load. Because of the small sample size, this observation could not be confirmed based on statistical tests. Future research should further examine this relationship between PAC, task load, and reliance on automation.

4.2   Gunnery Task Performance, Neutral Targets

It was found that the gunner's detection of neutral targets (which was not aided by AiTR) was significantly worse when s/he had to tele-operate a robotic asset (versus when the asset was semi-autonomous). This finding is consistent with previous research (Chen & Joyner, 2006; Chen & Terrence, 2007) and suggests that participants devoted significantly less visual attention to the gunnery station when their robotic asset required tele-operation. Our data also showed that those with a lower PAC performed at about the same level, regardless of the AiTR type, while those with a higher PAC had a significantly better performance with the MP cueing. This suggests that higher PAC participants devoted more visual attention to the gunnery station (implying a reduced reliance on automation for the gunnery task) when the AiTR was MP than when the AiTR was FAP. Although we did not measure participants' scanning behaviors, the detection rate of neutral targets on the gunnery station provides an estimate of the amount of operator's visual attention on the automated task environment. Again, the data of high PAC participants seem to support the hypothesis that MP automation reduces operator reliance. However, the same phenomenon was not observed for the low PAC participants.

4.3   Robotics Task Performance

For the robotics tasks, the data showed that participants had the best performance when the task was only monitoring the video feed. Moreover, the Monitor task performance stayed at the same level, regardless of the AiTR types. On the other hand, the Auto task performance was higher with the MP cueing, while the Teleop task performance was higher with the FAP cueing. The data of the Teleop performance are consistent with previous studies that MP automation degrades concurrent task performance more than FAP (Dixon & Wickens, 2006; Wickens, Dixon, Goh et al., 2005). However, the same trend was not observed for the other two robotics tasks, which were less challenging than the Teleop task. Therefore, it appears that the adverse effect of MP automation on concurrent tasks is only manifest in more challenging task conditions. Our data also showed that again, there was a significant AiTR Type x PAC interaction. Consistent with the previous two performance measures (gunnery-hostile and gunnery-neutral), the low PAC participants exhibited a higher level of performance degradation with the MP conditions. The performance of the high PAC participants, on the other hand, showed a completely opposite trend. These results suggest that the high PAC participants' reduced compliance with the FAP alerts did not help them with their concurrent task, compared with the MP conditions; in fact, it resulted in a poorer targeting performance. Conversely, their reduced reliance on the MP alerts did not hurt their performance as did the FAP alerts. Overall, the low PAC participants showed the most pronounced adverse effect of MP alerts on concurrent performance. Conversely, the FAP alerts not only helped them with their automated task but also their concurrent task.

Taking the three main performance measures together (i.e., Gunnery task, Hostile Targets, Gunner task, Neutral Targets, and Robotics task), it appears that overall, for high PAC participants, FAP alerts were more detrimental than MP alerts. FAP alerts affected their automated task and the concurrent task. This finding is consistent with the conclusion of Dixon et al. (2007) that FAP degraded overall performance more than MP automation. However, it is worth noting that for low PAC participants, we observed the opposite pattern: MP automation was more harmful than FAP automation. The overall data suggest that low PAC participants had a higher trust in the automation system than did high PAC participants. It is likely that low PAC participants had more difficulty in performing multiple tasks concurrently and had to rely on automation when available. High PAC participants, on the other hand, tended to rely on their own multi-tasking ability to perform the tasks. It is interesting to note that there was no significant difference in the participants' self assessment of their trust in the AiTR system between high PAC and low PAC groups. Our results are consistent with past research (Lee & Moray, 1994; Lee & See, 2004) that self-confidence is a critical factor in mediating the effect of trust (in automation) on reliance (on the automatic system). Lee and Moray found that when self-confidence exceeded trust, operators tended to use manual control. When trust exceeded self-confidence, automation was used more. Further research should be conducted to examine the relationships between PAC, self-confidence, and trust in automation.

4.4   Communication Task Performance

Participants' communication task performance was significantly better when their robotics task was Monitor than when it was Teleop. This finding is consistent with Chen and Joyner (2006). According to Naveh-Benjamin, Craik, Perretta, and Tonev (2000), information-encoding processes require more attention than retrieval and are more prone to the effects of competing demands of multi-tasking. It is therefore likely that the information-encoding process of the communication task in our study was more disrupted by the more challenging Teleop task than by the Monitor task.

4.5   Perceived Workload

Participants' perceived workload was found to be affected by the type of concurrent robotics task. The workload was significantly higher in the Teleop condition than in the Auto condition, which in turn was significantly higher than in the Monitor condition. These results are consistent with Chen and Joyner (2006) and Schipani (2003), which evaluated robotic operator workload in a field setting. Although many of the ground robotic assets in the Army's FCS program will be semi-autonomous, tele-operation will still be an important part of any missions involving robotic assets (e.g., when robots encounter obstacles or other problems). The higher workload associated with tele-operation needs to be taken into account when one is designing the user interfaces for the robotic assets (see Chen, Haas, & Barnes, 2007, for a review of user interface designs for tele-operated robots).

4.6   AiTR Display Preference

The significant positive correlation of AiTR preference with SpA is interesting. It appeared that as AiTR ratings tended toward considerable reliance on the tactile display, there was a concurrent shift with higher performance on the spatial tests. This confirmed a trend that was first observed in Chen and Terrence (2007). Perhaps those with higher SpA can more easily employ the spatial tactile signals in the dual task setting and therefore have a stronger preference for something that makes the gunner task easier to complete. Individuals with lower SpA, on the other hand, may have not used the spatial tactile cues to their full extent and therefore continued to prefer the visual AiTR display. According to Kozhevnikov Hegarty, and Mayer (2002), visualizers with lower SpA tend to rely on iconic imagery while those with higher SpA tend to prefer using spatial-schematic imagery to solve problems. Therefore, it is likely that in our study, those who preferred visual AiTR displays might be more iconic in their mental representations. However, this preference may have caused degraded target detection performance because more visual attention was devoted to the visual AiTR display than to the simulated environment. In contrast, those who were more spatial relied on the directional information of the tactile display to help them with the visually demanding tasks, resulting in a more effective performance.

5. Conclusions

In this study, we simulated a generic mounted environment and conducted an experiment to examine the performance and workload of the combined position of gunner and robotics operator. More specifically, we investigated the effects of AiTR with imperfect reliability (FAP versus MP) on the operator's performance of the automated (i.e., gunnery) task as well as the concurrent tasks (i.e., robotics and communication). Our data suggest that there is a strong interaction between the type of AiTR unreliability and participants' PAC for almost all the performance measures (except for the communication task, which showed the same trend but the interaction was not statistically significant). Overall, it appears that for high PAC participants, FAP alerts were more detrimental than MP alerts. FAP alerts affected not only their automated task but also the concurrent task. However, for low PAC participants, MP automation was more harmful than FAP automation. Future research should incorporate performance-based measures of attentional shifting effectiveness (e.g., Synthetic Work Environment or SYNWORK) in addition to surveys such as the ACS (Branscome & Grynovicki, 2007). In the area of SpA, the current study replicated the finding of Chen and Terrence (2007) that the operator's preference of AiTR display (i.e., visual versus tactile) is correlated with his or her SpA. Low SpA individuals prefer visual cueing over tactile cueing, although tactile display would be more effective in highly visual environments (so visual attention can be devoted to the tasks, not to the cues). These findings may have important implications for personnel selection, system designs, and training development. For example, to better enhance the task performance for low SpA individuals, the visual cueing display should be more integrated with the visual scene. Augmented reality (i.e., visual overlays) is a potential technique to embed directional information onto the video (Calhoun & Draper, 2006). Additionally, the capabilities and limits of the automated systems should be conveyed to the operator, when feasible, in order for the operator to develop appropriate trust and reliance (Lee & See, 2004).

6. References

Biros, D. P.; Daly, M.; Gunsch, G. The Influence of Task Load and Automation Trust on Deception Detection. *Group Decision and Negotiation* **2004**, *13*, 173-189.

Branscome, T. A.; Grynovicki, J. O. *An Investigation of Factors Affecting Multi-task Performance in an Immersive Environment*; ARL-TR-4325; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2007.

Calhoun, G.; Draper, M. *Multi-Sensory Interfaces for Remotely Operated Vehicles*. In N. Cooke, H. Pringle, H. Pedersen, & O. Connor (Eds.), Human factors of remotely operated vehicles (pp. 149-163), Oxford, UK: Elsevier, 2006.

Chen, J. Y. C.; Durlach, P.; Sloan, J.; Bowens, L. Human Robot Interaction in the Context of Simulated Route Reconnaissance Missions. *Military Psychology*, in press.

Chen, J. Y. C.; Haas, E. C.; Barnes, M. J. Human Performance Issues and User Interface Design for Teleoperated Robots. *IEEE Transactions on Systems, Man, and Cybernetics--Part C: Applications and Reviews* **2007**, *37*, 1231-1245.

Chen, J. Y. C.; Joyner, C. T. *Concurrent Performance of Gunner's and Robotic Operator's Tasks in a Simulated MCS Environment*; ARL-TR-3815; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2006.

Chen, J. Y. C.; Terrence, P. I. *Effects of Tactile Alerts on Concurrent Performance of the Gunner's and Robotic Operator's Tasks in a Simulated Mounted Environment*; ARL-TR-4227; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2007.

Derryberry, D.; Reed, M. A. Anxiety-Related Attentional Biases and Their Regulation by Attentional Control. *Journal of Abnormal Psychology* **2002**, *111* (2), 225-236.

Dixon, S. R.; Wickens, C. D. Automation Reliability in Unmanned Aerial Vehicle Control: A Reliance-Compliance Model of Automation Dependence in High Workload. *Human Factors* **2006**, 48, 474-486.

Dixon, S. R.; Wickens, C. D.; McCarley, J. S. On the Independence of Compliance and Reliance: Are Automation False Alarms Worse Than Misses? *Human Factors* **2007**, *49*, 564-572.

Educational Testing Service. *Cube Comparison Test*. Princeton, NJ: ETS, 2007a.

Educational Testing Service. *Hidden Figures and Hidden Patterns Tests*. Princeton, NJ: ETS, 2007b.

Gugerty, L.; Brooks, J. Reference-Frame Misalignment and Cardinal Direction Judgments:
Group Differences and Strategies. *Journal of Experimental Psychology: Applied* **2004**, *10*
(2), 75-88.

Hart, S.; Staveland, L. *Development of NASA TLX (Task Load Index): Results of Empirical and
Theoretical Research*. In P. Hancock & N. Meshkati (Eds.), Human Mental Workload (pp.
139-183). Amsterdam: Elsevier, 1988.

Jian, J. Y.; Bisantz, A. M.; Drury, C. G. Foundations for An Empirically Determined Scale of
Trust in Automated Systems. *International Journal of Cognitive Ergonomics* **2000**, *4*, 53-
71.

Kahneman, D., Ben-Ishai, R.; Lotan, M. Relation of a Test of Attention to Road Accidents.
Journal of Applied Psychology **1973**, *58*, 113-115.

Kozhevnikov, M.; Hegarty, M.; Mayer, R. E. Revising the Visualizer-Verbalizer Dimension:
Evidence for Two Types of Visualizers. *Cognition & Instruction* **2002**, *20* (1), 47-77.

Lathan, C.E.; Tracey, M. The Effects of Operator Spatial Perception and Sensory Feedback on
Human-Robot Teleoperation Performance. *Presence* **2002**, *11,* 368-377.

Lee, J. D.; Moray, N. Trust, Self-Confidence, and Operators' Adaptation to Automation.
International Journal of Human-Computer Studies **1994**, *40*, 153-184.

Lee, J. D.; See. K. A. Trust in Automation: Designing for Appropriate Reliance. *Human
Factors* **2004**, *46*, 50-80.

Mitchell, D. K. *Soldier Workload Analysis of the Mounted Combat System (MCS) Platoon's Use
of Unmanned Assets*; ARL-TR-3476; U.S. Army Research Laboratory: Aberdeen Proving
Ground, MD, 2005.

Naveh-benjamin, M.; Craik, F. I. M.; Perretta, J. G.; Tonev, S. T. The Effects of Divided
Attention on Encoding and Retrieval Processes: The resiliency of retrieval processes. *The
Quarterly Journal of Experimental Psychology* **2000**, *53A*, 609-625.

Noyes, J. M.; Bruneau, D. P. A Self-Analysis of the NASA-TLX Workload Measure.
Ergonomics **2007**, *50*, 514-519.

Rubinstein, J.S.; Meyer, D.E.; Evans, J.E. Executive Control of Cognitive Processes in Task
Switching. *Journal of Experimental Psychology: Human Perception and Performance*
2001, *27*, 763-797.

Schipani, S. An Evaluation of Operator Workload During Partially Autonomous Vehicle
Operations. *Proceedings of PerMIS 2003* **2003**.

Schumacher E.H.; Seymour, T.L.; Glass, J. M.; Fencsik, D.E.; Lauber, E.J.; Kieras, D.E. et al. 2001, Virtually Perfect Time Sharing in Dual-Task Performance: Uncorking the Central Cognitive Bottleneck. *Psychological Science* **2001**, *12*, 101-108.

Thomas, L.; Wickens, C. Eye-Tracking and Individual Differences in Off-Normal Event Detection When Flying With a Synthetic Vision System Display. *Proceedings of the Human Factors and Ergonomics Society 48th Meeting* (pp. 223-227), 2004.

TRADOC. *The United States Army Objective Force Operational and Organizational Plan Maneuver Unit of Action*; TRADOC Pamphlet 525-3-90 O&O; Unit of Action Maneuver Battle Lab: Fort Knox, KY, 2003.

Wickens, C. D.; Dixon, S. R. *Is There a Magic Number 7 (to the Minus 1)? The Benefits of Imperfect Diagnostic Automation: A Synthesis of the Literature*;Tech. Report AHFD-05-01/MAAD-05-01; University of Illinois, Institute of Aviation, Aviation Human Factors Division: Urbana-Champaign, IL, 2005. Retrieved May 15, 2006, from http://www.human factors.uiuc.edu/Reports&PapersPDFs/TechReport/05-01.pdf.

Wickens, C. D.; Dixon, S. R.; Goh, J.; Hammer, B. *Pilot Dependence on Imperfect Diagnostic Automation in Simulated UAV Flights: An Attentional Visual Scanning Analysis*; Tech. Report AHFD-05-02/MAAD-05-02; University of Illinois, Institute of Aviation, Aviation Human Factors Division: Urbana-Champaign, IL, 2005. Retrieved December 15, 2005, from http://www.humanfactors.uiuc.edu/Reports&PapersPDFs/TechReport/05-02.pdf.

Wickens, C. D.; Dixon, S. R.; Johnson N. *UAV Automation: Influence of Task Priorities and Automation Imperfection in a Difficult Surveillance Task*; Tech. Report AHFD-05-20/MAAD-05-6; University of Illinois, Institute of Aviation, Aviation Human Factors Division: Urbana-Champaign, IL, 2005. Retrieved December 15, 2005, from http://www.human factors.uiuc.edu/Reports&PapersPDFs/TechReport/05-20.pdf.

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Appendix A. Demographic Questionnaire

Participant # _____   Age _____   Major _____   Date _____   Gender ___

1. What is the <u>highest</u> level of education you have had?
Less than 4 yrs of college _____   Completed 4 yrs of college _____   Other _____

2. When did you use computers in your education? (*Circle all that apply*)

       Grade School   Jr. High   High School
       Technical School   College   Did Not Use

3. Where do you currently use a computer? (*Circle all that apply*)

Home   Work   Library   Other_____   Do Not Use

4. For each of the following questions, <u>circle</u> the response that best describes you.

    How often do you:

Use a mouse?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use a joystick?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use a touch screen?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use icon-based programs/software?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use programs/software with pull-down menus?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use graphics/drawing features in software packages?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Use E-mail?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Operate a radio controlled vehicle (car, boat, or plane)?	Daily, Weekly, Monthly, Once every few months, Rarely, Never
Play computer/video games?	Daily, Weekly, Monthly, Once every few months, Rarely, Never

5. Which type(s) of computer/video games do you most often play if you play at least once every few months?

6. Which of the following best describes your expertise with computer? (check √ one)
     _____ Novice
     _____ Good with one type of software package (such as word processing or slides)
     _____ Good with several software packages
     _____ Can program in one language and use several software packages
     _____ Can program in several languages and use several software packages

7. Are you in your usual state of health physically?   YES   NO
    If NO, please briefly explain:

8. How many hours of sleep did you get last night? _____ hours

9. Do you have normal color vision? YES   NO

10. Do you have prior military service? YES   NO   If Yes, how long _____

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Appendix B. Attentional Control Survey

For each of the following questions, <u>circle</u> the response that best describes you.

It is very hard for me to concentrate on a difficult task when there are noises around.
Almost never, Sometimes, Often, Always

When I need to concentrate and solve a problem, I have trouble focusing my attention.
Almost never, Sometimes, Often, Always

When I am working hard on something, I still get distracted by events around me.
Almost never, Sometimes, Often, Always

My concentration is good even if there is music in the room around me.
Almost never, Sometimes, Often, Always

When concentrating, I can focus my attention so that I become unaware of what's going on in the room around me.
Almost never, Sometimes, Often, Always

When I am reading or studying, I am easily distracted if there are people talking in the same room.
Almost never, Sometimes, Often, Always

When trying to focus my attention on something, I have difficulty blocking out distracting thoughts.
Almost never, Sometimes, Often, Always

I have a hard time concentrating when I'm excited about something.
Almost never, Sometimes, Often, Always

When concentrating, I ignore feelings of hunger or thirst. Almost never, Sometimes, Often, Always

I can quickly switch from one task to another.   Almost never, Sometimes, Often, Always

It takes me a while to get really involved in a new task.   Almost never, Sometimes, Often, Always

It is difficult for me to coordinate my attention between the listening and writing required when taking notes during lectures.   Almost never, Sometimes, Often, Always

I can become interested in a new topic very quickly when I need to.
Almost never, Sometimes, Often, Always

It is easy for me to read or write while I'm also talking on the phone.
Almost never, Sometimes, Often, Always

I have trouble carrying on two conversations at once.   Almost never, Sometimes, Often, Always

I have a hard time coming up with new ideas quickly.   Almost never, Sometimes, Often, Always

After being interrupted or distracted, I can easily shift my attention back to what I was doing before.
Almost never, Sometimes, Often, Always

When a distracting thought comes to mind, it is easy for me to shift my attention away from it.
Almost never, Sometimes, Often, Always

It is easy for me to alternate between two different tasks. Almost never, Sometimes, Often, Always

It is hard for me to break from one way of thinking about something and look at it from another point of view.
Almost never, Sometimes, Often, Always

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Appendix C. NASA TLX Questionnaire

Please rate your <u>overall</u> impression of demands imposed on you during the exercise.

1. Mental Demand: How much mental and perceptual activity was required (e.g., thinking, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

<div align="center">

LOW |---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

</div>

2. Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

<div align="center">

LOW |---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

</div>

3. Temporal Demand: How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

<div align="center">

LOW |---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

</div>

4. Level of Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

<div align="center">

LOW |---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

</div>

5. Level of Frustration: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

<div align="center">

LOW |---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

</div>

6. Performance: How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

<div align="center">

LOW |---|---|---|---|---|---|---|---|---| HIGH
1 2 3 4 5 6 7 8 9 10

</div>

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Appendix D. Usability Questionnaire

1. The gunner station should only have the visual ATR display.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A   Comments
                       1   2   3   4   5   6   7

2. The gunner station should only have the tactile ATR display.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                       1   2   3   4   5   6   7

3. I made use of both the visual and tactile ATR displays.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                       1   2   3   4   5   6   7

4. I sometimes felt 'lost' using the tactile ATR display.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                       1   2   3   4   5   6   7

5. I sometimes felt 'lost' using the visual+tactile display.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                       1   2   3   4   5   6   7

6. The tactile ATR display was intuitive and made it easy to
     determine the direction of targets.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                       1   2   3   4   5   6   7

7. The visual+tactile ATR display was intuitive and made it easy to
     determine the direction of targets.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                       1   2   3   4   5   6   7

8. **I do not feel either ATR display (tactile or visual+tactile) was helpful in the gunner task.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                  1 2 3 4 5 6 7

9. **The tactile ATR display was helpful when I had to teleoperate the UGV.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                  1 2 3 4 5 6 7

10. **I relied heavily on the tactile ATR display for the gunner task.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                  1 2 3 4 5 6 7

11. **I relied heavily on the visual+tactile ATR display for the gunner task.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                  1 2 3 4 5 6 7

12. **The tactile ATR display was helpful when the UGV was semi-autonomous.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                  1 2 3 4 5 6 7

13. **The visual+tactile ATR display was helpful when I had to teleoperate the UGV.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                  1 2 3 4 5 6 7

14. **The visual+tactile ATR display was helpful when the UGV was semi-autonomous.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                  1 2 3 4 5 6 7

15. **The gunner station should not have an ATR display.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                  1 2 3 4 5 6 7

16. **The tactile ATR display was confusing.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                  1 2 3 4 5 6 7

17. **The visual+tactile ATR display was confusing.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                  1 2 3 4 5 6 7

18. **The tactile ATR display was annoying.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                  1 2 3 4 5 6 7

19. **The visual+tactile ATR display was annoying.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                  1 2 3 4 5 6 7

20. The tactile ATR display improved my performance on the gunner task.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                      1   2   3   4   5   6   7

21. The visual+tactile ATR display improved my performance on the gunner task.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                      1   2   3   4   5   6   7

22. The visual+tactile ATR display can be deceptive**.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                      1   2   3   4   5   6   7

23. The visual+tactile ATR display sometimes behaves in an unpredictable manner.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                      1   2   3   4   5   6   7

24. I am often suspicious of the **visual+tactile ATR system's** intent, action, or outputs.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                      1   2   3   4   5   6   7

25. I am sometimes unsure of the **visual+tactile ATR system.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                      1   2   3   4   5   6   7

26. The **visual+tactile ATR system may have harmful effects on the gunnery task.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                      1   2   3   4   5   6   7

27. I am confident in the **visual+tactile ATR system.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                      1   2   3   4   5   6   7

28. The visual+tactile ATR system can provide security.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                          1   2   3   4   5   6   7

29. The visual+tactile ATR system has integrity.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                          1   2   3   4   5   6   7

30. The visual+tactile ATR system is dependable.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                          1   2   3   4   5   6   7

31. The visual+tactile ATR system is consistent.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                          1   2   3   4   5   6   7

32. I can trust the visual+tactile ATR system.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                          1   2   3   4   5   6   7

33. I am familiar with the visual+tactile ATR display.
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                          1   2   3   4   5   6   7

**34. The visual+tactile ATR display improved my performance on the
    gunner task.**
Strongly DISAGREE |----|----|----|----|----|----| Strongly AGREE   N/A
                          1   2   3   4   5   6   7

Which of the following best describes your source of AITR information when you had access to both the visual and the tactile displays (please circle ONE answer only):

1. entirely visual
2. predominately visual
3. both visual and tactile
4. predominately tactile
5. entirely tactile

Appendix E. Complete Gunnery Performance Data (hostile targets)

	AiTR	SpA	PAC	Mean	Std. Deviation	N
Gunnery Task (Hostile Targets)- Auto Condition	FAP	Low	Low	.5750	.09574	4
			High	.2500	.07071	2
			Total	.4667	.18619	6
		High	Low	1.0000	.	1
			High	.5622	.38144	5
			Total	.6352	.38515	6
		Total	Low	.6600	.20736	5
			High	.4730	.34790	7
			Total	.5509	.30154	12
	MP	Low	Low	.6500	.35355	2
			High	.5500	.28868	4
			Total	.5833	.27869	6
		High	Low	.4200	.08367	5
			High	.8000	.	1
			Total	.4833	.17224	6
		Total	Low	.4857	.19518	7
			High	.6000	.27386	5
			Total	.5333	.22697	12
	Total	Low	Low	.6000	.17889	6
			High	.4500	.27386	6
			Total	.5250	.23404	12
		High	Low	.5167	.24833	6
			High	.6018	.35471	6
			Total	.5592	.29530	12
		Total	Low	.5583	.21088	12
			High	.5259	.31236	12
			Total	.5421	.26116	24
Gunnery Task (Hostile	FAP	Low	Low	.6444	.18592	4

				Mean	Std. Dev	N
			High	.3750	.17678	2
			Total	.5546	.21529	6
		High	Low	1.0000	.	1
			High	.6800	.27749	5
			Total	.7333	.28048	6
		Total	Low	.7156	.22630	5
			High	.5929	.28052	7
			Total	.6440	.25600	12
	MP	Low	Low	.3000	.28284	2
			High	.5750	.33040	4
			Total	.4833	.31885	6
		High	Low	.4400	.16066	5
			High	.9000	.	1
			Total	.5167	.23647	6
		Total	Low	.4000	.18764	7
			High	.6400	.32094	5
			Total	.5000	.26820	12
	Total	Low	Low	.5296	.26149	6
			High	.5083	.28708	6
			Total	.5190	.26204	12
		High	Low	.5333	.27003	6
			High	.7167	.26394	6
			Total	.6250	.27199	12
		Total	Low	.5315	.25343	12
			High	.6125	.28455	12
			Total	.5720	.26675	24
Gunnery Task (Hostile Targets)- Monitor Condition-	FAP	Low	Low	.7750	.32016	4
			High	.5000	.00000	2
			Total	.6833	.28577	6
		High	Low	1.0000	.	1
			2	.8400	.15166	5
			Total	.8667	.15055	6

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				Mean	Std. Dev	N
		Total	Low	.8200	.29496	5
			High	.7429	.20702	7
			Total	.7750	.23789	12
	MP	Low	Low	.5000	.14142	2
			High	.5750	.17078	4
			Total	.5500	.15166	6
		High	Low	.6400	.15166	5
			High	.8000	.	1
			Total	.6667	.15055	6
		Total	Low	.6000	.15275	7
			High	.6200	.17889	5
			Total	.6083	.15643	12
	Total	Low	Low	.6833	.29269	6
			High	.5500	.13784	6
			Total	.6167	.22896	12
		High	Low	.7000	.20000	6
			High	.8333	.13663	6
			Total	.7667	.17753	12
		Total	Low	.6917	.23916	12
			High	.6917	.19752	12
			Total	.6917	.21451	24

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Acronyms

ANOVA   analysis of variance

ARL   Army Research Laboratory

AiTR   aided target recognition

CR   correct rejection

FA   false alarm

FAP   false alarm prone

FCS   Future Combat System

FOV   field of view

IMPRINT   Improved Performance Research Integration Tool

LOS   line of sight

LSD   least significant difference

MCS   mounted combat system

MP   miss prone

NASA TLX   National Aeronautics and Space Administration Task Load Index

OCU   operator control unit

OTW   out the window

PAC   perceived attentional control

RCTA   Robotics Collaborative Technology Alliance

RSTA   reconnaissance, surveillance, and target acquisition

SIL   system integration laboratory

SpA   spatial ability

SSQ   Simulator Sickness Questionnaire

TCU   tactical control unit

TS   total severity

TSS	Total Severity Score
UCD	unmanned combat demonstration
UCF	University of Central Florida
UGV	unmanned ground vehicle
XUV	experimental unmanned vehicle

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